Water clarity in Lake Itasca: Bottom-up vs. Top-down theory

Mark Dube, Desiree Strelow, & Rachel Woods

Itasca Biological Station & Laboratories, University of Minnesota, Itasca, MN.

Abstract

Lake Itasca is clearer than normal for spring and expected to become less clear as the summer progresses, due to algal growth. Our research investigated the main factor that controls water clarity in Lake Itasca based on two different theoretical concepts: Bottom-up versus Top-down effects. Ultimately, we inferred that the top-down theory was the main influence, in which food web interactions were the largest driver of water clarity. We examined the abundance of zooplankton, hatching of yellow perch larvae, and algal levels in conjunction with nutrient levels to support our hypothesis. The zooplankton population declined in correlation to the presence of larval yellow perch, along with growth in the amount of chlorophyll at each site, presented evidence in food web change. Nitrate levels showed consistency and no pattern of change, further providing support towards our hypothesis. These results of our research supported our hypothesis in that the Top-down theory was the main controller on water clarity in Lake Itasca.

Key Concepts: Bottom-up; Top-down

Introduction

For the spring of 2008, Lake Itasca has been clearer than usual. To investigate the causes for this, we used two basic theories that are hypothesized to control water clarity. The "Bottom-up" theory states that nutrient levels affect algal growth, which ultimately affects the clarity in the water. In contrast, the “Top-down” theory hypothesizes water clarity to be affected by the structure of the food web within the lake ecosystem. For the purpose of our study, this directly involves the amount of phytoplankton being affected by zooplankton feeding, and yellow perch larvae shaping the abundance of zooplankton. We predicted that the top-down theory was the main influence for water clarity in Lake Itasca. Our research tested the two hypotheses in order to determine the main cause for water clarity in the lake.

“Bottom-up” and “Top-down” actions influence populations and communities in lake ecosystems, and are determined by investigating the interactions occurring between these populations (Hunter, 1992). The “Bottom-up” theory argues that nutrient levels are the main control in algal concentrations, effecting water clarity in the lake. If patterns of change were seen in the nutrient levels, this would lead one to assume the “Bottom-up” over “Top-down” theory. We argued that the “Top-down” theory was the main factor determining water clarity, because of the cold-water, late spring taking place in Lake Itasca for 2008 affecting yellow perch spawning.

The clear-water period is a distinctive time when algal growth is lower than expected, early in the spring (Lampert, 1986). This “late spring clear-water” phase affects the hatching of yellow perch and zooplankton populations. The late arrival of spring and colder water temperatures in Lake Itasca delayed the spawning and hatching of yellow perch larvae that typically feed on zooplankton. Ideal water temperatures for yellow perch hatching range from 10°C to 15°C (Whiteside, 1985). In Lake Itasca, yellow perch are one of the dominant fish species that typically feed and rely on the zooplankton populations for food (Whiteside, 1985). If the perch prematurely hatched, this would leave a higher population of zooplankton left to feed on the algae, making the water become clearer. The relationship between zooplankton and larval yellow perch is vital for food web interactions, concerning the abundance and growth of algae in the lake (Whiteside, 1985). In applying this to our research, we could predict that the "Top-down" theory could be a bigger force in causing water clarity.

Methods

Overview

During the month of June 2008, we tested the northern and eastern arms in two specific areas of Lake Itasca, one day per week, four weeks total. (Fig.1) Our collections mainly took place on a motorboat using key equipment and supplies. Samples were drawn of water temperature, dissolved oxygen levels, Secchi depth, chlorophyll, nutrients, zooplankton, and larval yellow perch in order to gather results.

Study Site

The study took place in Lake Itasca, MN, at the University of Minnesota Itasca Biological Station and Laboratories. Lake Itasca is the headwaters of the Mississippi River, located in northwestern Minnesota, Itasca State Park. The average depth of the lake varies from 20-35 feet (MN DNR).

Temperature & Dissolved Oxygen

Temperature (°C) and dissolved oxygen content were taken at both the north arm site and east arm site with a YSI Model 85 probe. Recordings were taken every meter until the probe hit the bottom. The temperature and dissolved oxygen levels were examined to estimate the stratification levels.

Secchi Depth & Water Clarity

Water clarity was tested at both the north arm site and the east arm site using a Secchi disk. The disk was lowered into the water until the disk was no longer visible, giving us a water clarity depth, allowing us to visualize the change over the month.

Chlorophyll and Nutrient Collection

We collected chlorophyll / algae and nutrients using a VanDorm water sampler from depths at both the north arm site and the east arm site. On 6.4.08, samples were taken from the epilimnion and metalimnion layers at the north arm site, and the hypolimnion form the east arm site. On 6.12.08 and 6.18.08 samples were taken just from the epilimnion at each location. On 6.23.08 samples were taken from all three layers at each location. The samples were labeled and stored in plastic containers that were refrigerated until filtration. A water filtration pump was used to obtain the algae. Filters were then wrapped in tin foil and labeled, frozen until testing for chlorophyll could be done. The chlorophyll pigments were extracted from the filters, diluted with 95% ethanol, centrifuged and then tested with a spectrophotometer to acquire data on chlorophyll levels. We then obtained nutrient data using the filtered water by using nutrient testing kits (*Hach Kits*) to collect nitrate and phosphate levels. (Holm-Hansen & Reimann, 1978)

Zooplankton

Zooplankton were collected and identified, in order to estimate population size in the lake. Replicate samples were taken on 6.4.08 from the epilimnion and metalimnion at the north arm site, and the hypolimnion at the east arm site. On 6.12.08 and 6.18.08 whole water column replicate samples were taken at each site. On 6.23.08 replicate samples were taken from all three layers and both sites on the lake. The samples were placed into labeled containers and diluted with 95% ethanol to kill all zooplankton in the sample. (Huspeni, 1986). To test for zooplankton abundance, each sample was emptied into a beaker, and diluted with water till approximately 100 mL. Three 1mL samples were extracted and placed onto a slide and observed under a microscope. We examined and counted the different species of zooplankton, then used the following equation to determine the abundance of zooplankton per Liter in the lake:

$$\frac{\#}{L} = \frac{\#/mLss \bullet Vd(mL)}{Vf}$$

In the equation, #/mLss represents the average of the species found in the three slide, Vd(mL) was the volume of water they were diluted and extracted from, and Vf represents the total volume of water of the lake they were sample from. 1m dragged in the lake equals 10L of water sampled.

Yellow Perch Larvae Collection

Seining nets were used to collect yellow perch larvae to determine spawning activity. We tested the area off of the University of Minnesota Itasca Biological Station and Laboratories' boat docks about two times every week. The first attempts were done off of a boat using a dip net along shallow areas in the reed beds. Later attempts were done using a fine seining net along the shallow reed bed off of the docks. After collections, we were able to correlate the presence of larvae hatching in relation to the amount of zooplankton within the lake.

Results

Secchi depth & Water Clarity

The Secchi depth measuring water clarity decreased over the month of June (Table 1). At the north arm site, water clarity was high at approximately 6.5m on 6.4.08, and ending at 3m on 6.23.08. Similar declines in water clarity were observed at the east arm location.

Temperature & Dissolved Oxygen

Water temperature decreased for both the north arm site and the east arm site as the month progressed. (Fig. 2) Dissolved oxygen also decreased throughout the month, but with slightly more overlap of numbers on a weekly basis (Fig. 2) The data collected from the temperature and dissolved oxygen readings were then used to estimate the stratification layers in order to test for chlorophyll, nutrients, and zooplankton.

Chlorophyll concentrations

Chlorophyll concentrations at the north arm site gradually increased over the month at the epilimnion and the metalimnion. (Fig. 3) Data for the hypolimnion at the north arm site was only collected on 6.23.08. Chlorophyll concentrations at the east arm site only increased slightly for epilimnion layers (Fig. 3). Data for the metalimnion was only collected on 6.23.08 and on 6.4.08 for the hypolimnion at the east arm site.

Nutrient levels

Levels of nitrate stayed consistent for the north arm site and the east arm site throughout the month of testing (Fig. 4). At the north arm site, comparable data was taken from the epilimnion and the metalimnion. At the east arm site, comparable data was taken from the epilimnion and the hypolimnion. The sampling taken on 6.18.08 showed the lowest reading of nitrates, however standard deviation bars fell within the range of acceptance. Overall, the data showed no clear pattern or strong indication of growth or decrease at either site. The testing for the phosphate however showed inconsistent results in replicate sampling. Because of the obvious error, this led us to exclude to phosphate results from our data.

Zooplankton

Overall, zooplankton population density at the different stratification layers and whole water columns decreased as the month progressed, with a few exceptions (Fig. 5). The populations that slightly increased at the north arm included *Cyclopoids* at the epilimnion, and *Rotifera* at the metalimnion layer, between the first and last days measured. Additionally *Daphnia* and *Rotifera* increased for the entire water column from the second to third day at the eastern arm. All other zooplankton populations that decreased were identified as *Daphnia*, *Cyclopoid*, *Calanoid*, *Nauplii*, and *Rotifer*.

Yellow Perch Larvae

We collected the yellow perch larvae by seining along the shore and reed beds in shallow areas of the lake. In the beginning of the month no larval perch were found using the dip nets off of the boat. Towards the end of the month when we switched to fine seining nets, there was still no detection of larval yellow perch until 6.23.08. We found 35 larval perch, averaging in 14mm.

Discussion

Our research investigated the main controlling factor for water clarity in Lake Itasca by examining the Top-Down vs. Bottom-up theory. The results of our research supported our hypothesis in that the Top-down theory was the main determinant for water clarity in Lake Itasca.

The Chlorophyll concentrations gradually increased throughout the month of testing at both the north arm site and the east arm site. It is important to note that data was not taken from the epilimnion on 6.4.08 at the east arm site. If taken, we believe one would observe lower chlorophyll levels for that day, supporting our findings of increased chlorophyll levels throughout the entire month at the north arm site. The increase in chlorophyll concentrations were inversely proportional to the secchi depth readings we took, which showed a decrease in water clarity. The increase in chlorophyll shows an increase in algae, which would be the main factor in water clarity. We then had to look at nutrient and zooplankton levels to determine what was the cause of the increase in chlorophyll.

The nitrate levels showed no particular pattern of change throughout the month at both locations at multiple stratification levels. This led us to conclude that nitrate levels were not a leading factor in algal growth affecting water clarity. If nitrate levels were to significantly affect water clarity one would expect to see an increase in concentration, in correlation with the increasing algal levels. More nutrient levels would be needed to support an increasing algae population.

The zooplankton levels however dramatically decreased at both sites throughout the month. The largest sized zooplankton, *Daphnia*, *Cyclopoid*, and *Calanoid* were found to have the largest drop in population, where the smaller *Rotifera* actually increased in certain areas. Research has shown that planktivorious fish, such as larval yellow perch, are size selective in the zooplankton they will feed on, and as they increase in size they will continue to feed on the larger zooplankton (Whiteside, 1985). This explains why the larger zooplankton decreased in population dramatically, while the smaller sized Rotifera actual increased.

The findings of yellow perch are also consistent with previous research. After they hatch, yellow perch will migrate from the shallower littoral zone into the deeper limnetic zone in order to avoid predation. Here they will feed on the zooplankton found in these areas. After about 40 days, when they are between 14-25 mm, they will then migrate back to the littoral zone (Whiteside, 1985). It is in the littoral zone that we found the yellow perch, at an average size of 14 mm. Our assumption is that they had just begun their migration back and we caught the first group of them. We timed their hatching sometime mid-late may. The presence of yellow perch in the deeper limnetic zone would explain the decrease in zooplankton levels throughout the month.

The fact that a colder spring caused a delayed yellow perch spawning brings into question what will happen in the futures, especially in conjunction with global climate change. If global temperatures are continually rising, how will that affect the water clarity of Lake Itasca? We witnessed that a cold spring extended the clear water phase of Lake Itasca, and therefore can only hypothesize that a warmer spring would decrease the water clarity within the Lake. Yellow perch would begin spawning earlier, deceasing the zooplankton population sooner than normal, allowing the algae to grow, causing the lake to become less clear than years pass. This also brings into question the long-term affects. The lake, the living organisms within it, and the weather patterns of this area have reached equilibrium for themselves, and if something is changed one must wonder if the system can rebalance itself back out? Further research could continue to be done on the lake yearly to observe and record the changes in the data that we collected.

Some changes that could be done to our experiment would be to collect water samples for chlorophyll and nutrient testing at each stratification layer for each location on each day. Doing this would allow you to observe the change more closely, and allow you to arrive at a stronger conclusion. We would also have collected zooplankton at all the stratification layers for each location on each day, as well as whole water column collections at each location on each day. Again, this would allow you to observe the data more accurately and leave less room for error.

Conclusion

These results are consistent with research on clear-water periods in lakes caused by zooplankton feeding on algae (Lampert et al., 1986). Our results ultimately provide support in that yellow perch larvae fed on the zooplankton, decreasing the zooplankton population, and impacting the algal growth in the lake to make it become less clear. The late presence of yellow perch larvae coincides with a late spring season in Lake Itasca for 2008. On the basis of the Top-down theory, along with our research findings, provides evidence that the food web interactions were the largest driver for water clarity in Lake Itasca.

Literate Cited

Hembre, L.K., and R.O. Megard. 2005.*Timing of predation by rainbow trout controls Daphnia demography and the trophic status of a Minnesota lake.* Freshwater Biology. 50, 1064 1080.

Holm-Hansen, O., and B. Reimann. 1978. Chlorophyll a determination: improvements in methodology. Oikos. 30, 438-447.

Hunter, M.D., and P.W. Price. 1993. *Playing chutes and latters:Heterogeneity and the relative roles of bottom-up and top-down forces in natural communities.* Ecology. 73, 724-732.

Huspeni, T., and L.N. Kittelson. 1986. *Vertical Nocturnal Migration of Zooplankton in Lake Itasca.* University of Minnesota, Itasca Biological Station. IBS# 1784

Jeppesen, E.,J.P. Jensen, M. Sondergaard, and T. Lauridsen.1999. *Trophic dynamics in turbid and Clearwater lakes with special emphasis on the role of zooplankton for water clarity*. Hydrobiologia. 408/409, 217-231.

Lampert, W., W. Fleckner, H. Rai, and B.E. Taylor. 1986. *Phytoplankton control by grazing zooplankton: A story on spring clear-water phase.* Limnology and Oceanography. 31, 478-490.

Monahan, L.L.1992. *Variability of Chlorophyll Concentration in Lake Itasca*. University of Minnesota. Itasca Biological Station. IBS # 2275

Rudstam, L.G.,R.C. Lanthrop, and S.R. Carpenter.1993. *The Rise and Fall of a dominant Planktivoire: Direct and Indirect Effects on Zooplankton*. Ecology. 74, 303-319.

Whiteside, M.C., C.M. Swindoll, and W.L. Doolittle. 1985. *Factors affecting the early life history of yellow perch, Perca flavescens*. Biology of Fishes. 12, 47-56.

Other Sources

Minnesota Department of Natural Resources. 2008. The Minnesota Department of Natural Resources Web Site (online). Accessed 2008-6-27 at http://www.dnr.state.mn.us/sitetools/copyright.html

Date	Site	Secchi Depth (m)	Total Depth (m)
6/4/08	North Arm	>6.50	7.50
6/4/08	East Arm	-------	-------
6/12/08	North Arm	5.00	9.15
6/12/08	East Arm	4.25	14.34
6/18/08	North Arm	4.50	8.08
6/18/08	East Arm	4.00	14.49
6/23/08	North Arm	3.00	7.02
6/23/08	East Arm	2.50	13.88

Table 1 Secchi depth readings were taken throughout the month of June at both locations on Lake Itasca. At both locations the water clarity decreased on a weekly bases. Total lake depth was recorded.

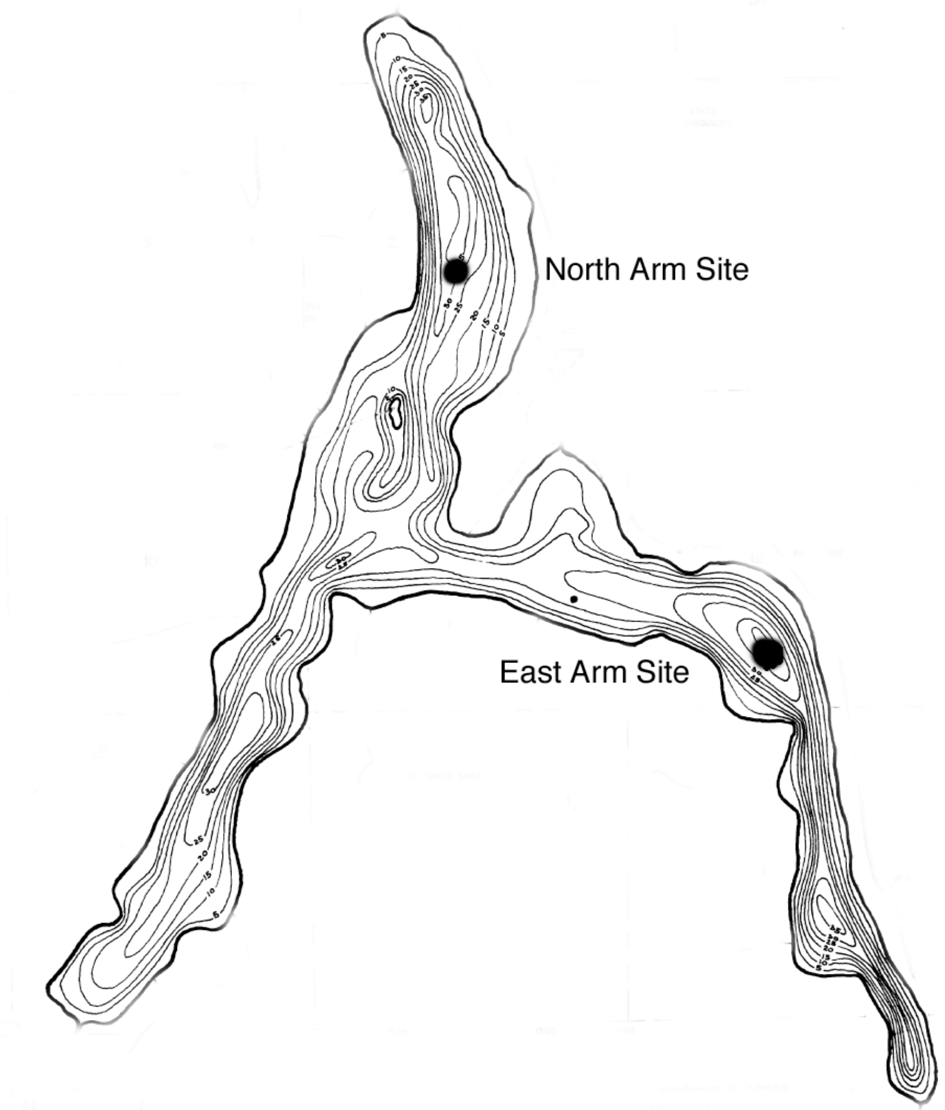


Fig. 1 Testing was done at two locations on Lake Itasca, one on the north arm, one on the east. The east arm test site was chosen because it is the deepest area on the lake, approximately 50ft.

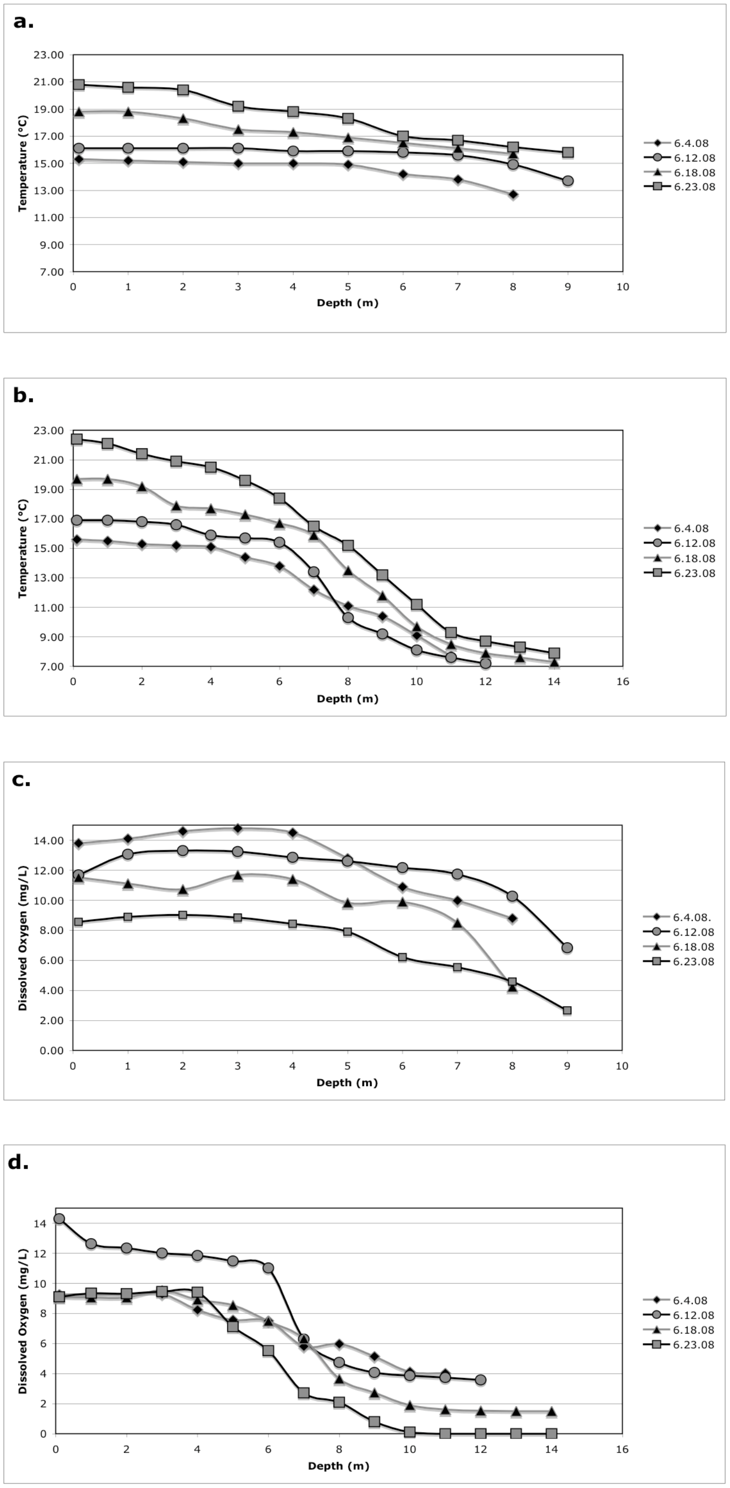
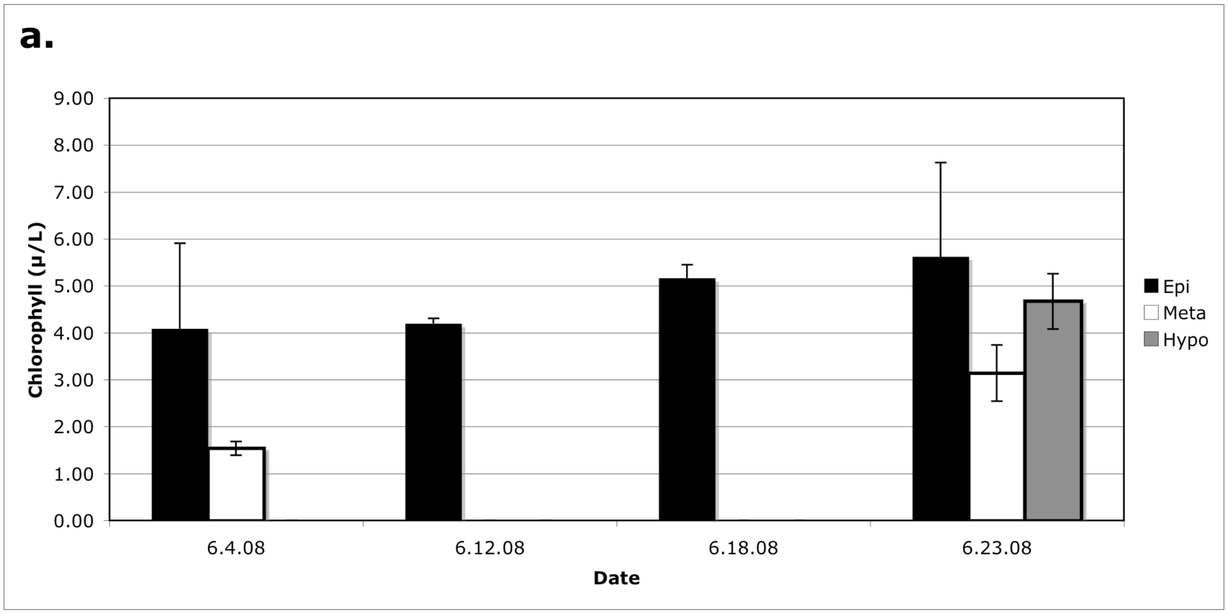


Fig. 2 Water temperature measurements from the north arm site (a.) and the east arm site (b.) were taken on a weekly basis throughout the month of June. Warmer temperatures were noticed at each location at meter intervals throughout the month. Dissolved oxygen readings were taken from the north arm site (c.) and the east arm site (d.). Temperature and dissolved oxygen readings were used to determine the Metalimnioin and Hypolimnion layers.



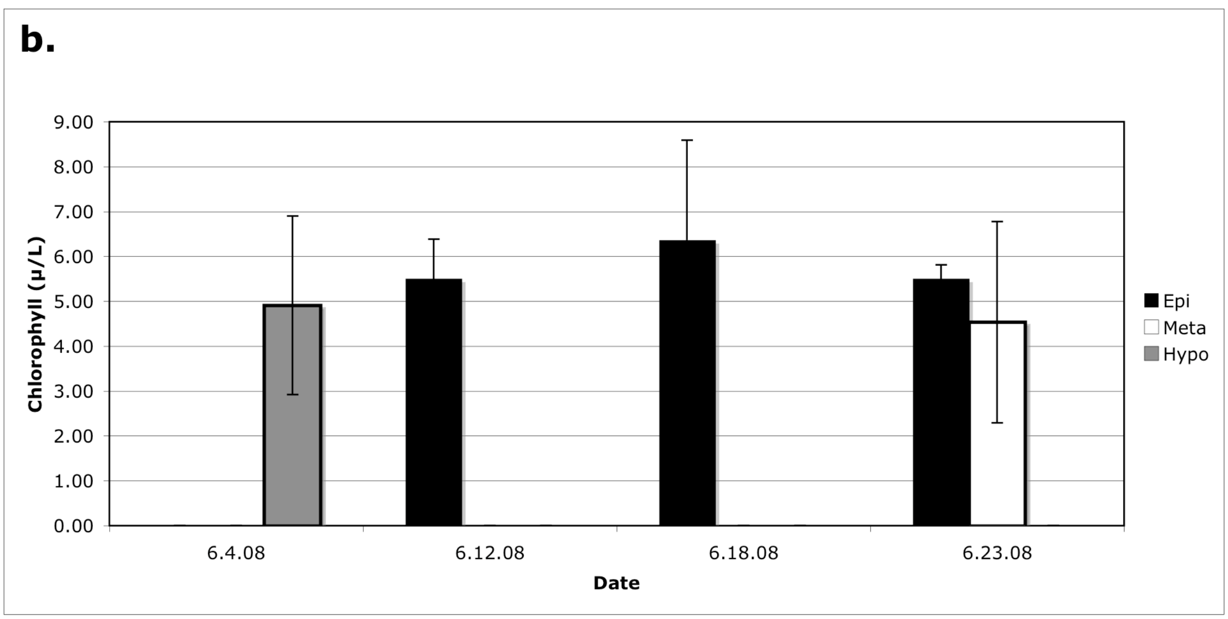
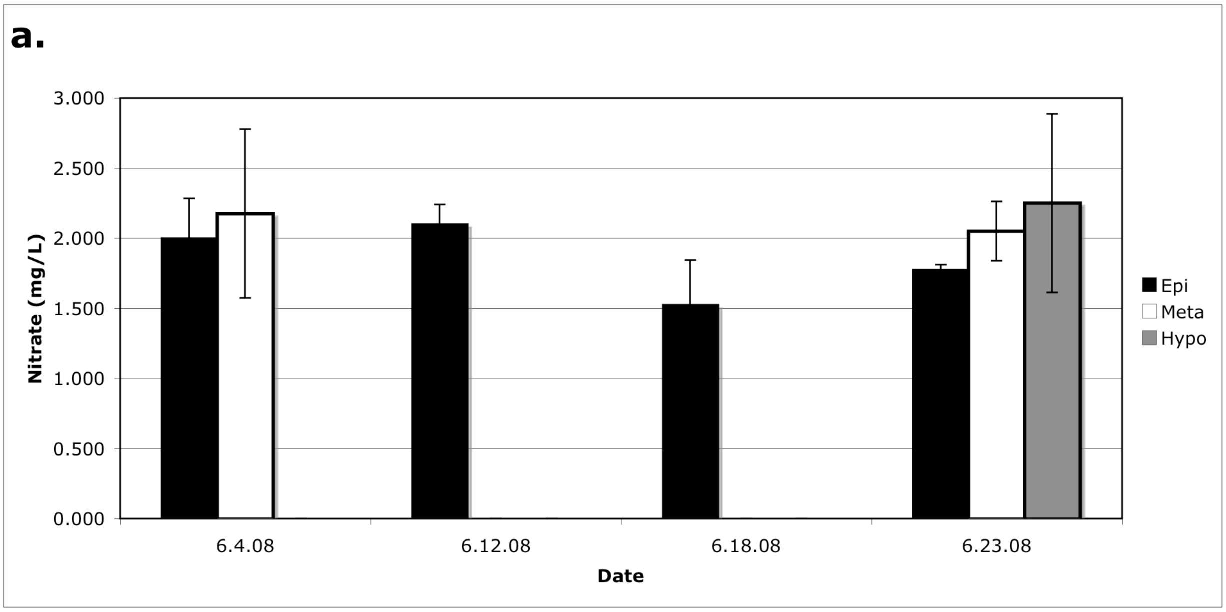


Fig. 3 Chlorophyll testing was done at the north arm site (a.) and the east arm site (b.) on a weekly basis throughout the month of June. An increase is clearly noticed at the north arm site. Data wasn't taken at the Epilimion from the east arm site on 6.4.08, which is predicted to be a lower concentration, showing more of an increase at the east arm location. Chlorophyll concentrations increased at the Metalimnion at the north arm site.



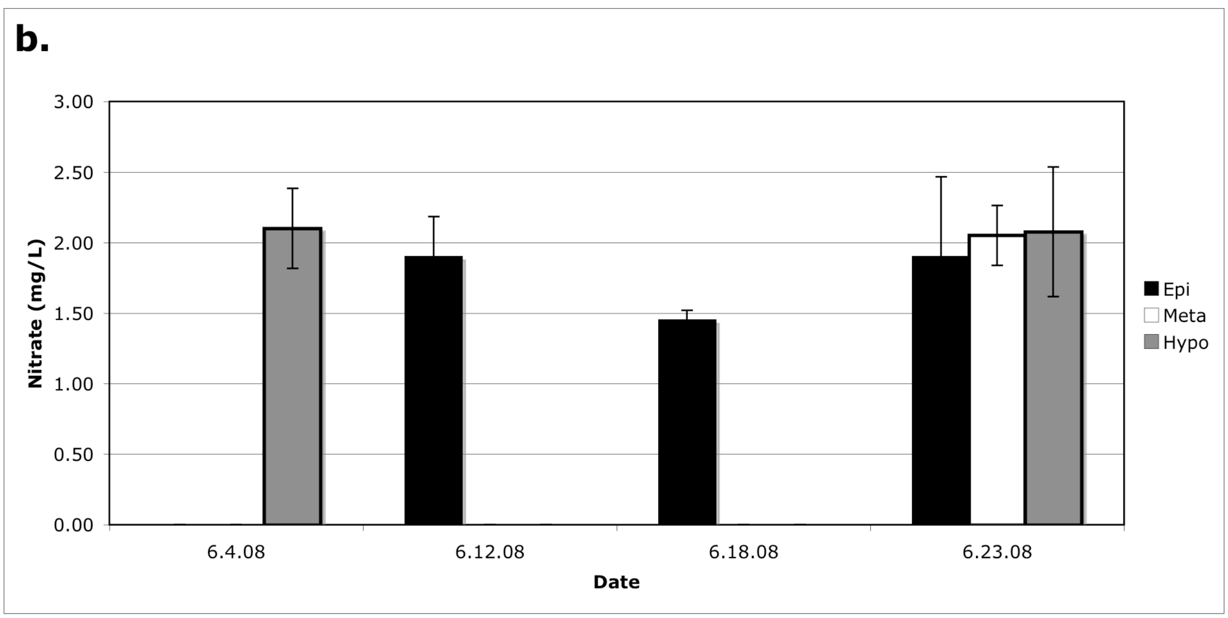


Fig. 4 Nitrate concentrations were calculated from the north arm site (a.) and the east arm site (b.) on a weekly basis over the course of the month of June. Levels remained relatively constant at both sites excluding the data taken on 6.18.08, which resulted in a lower reading. Data was not collected at the Epilimnion for the east arm site and 6.4.08.

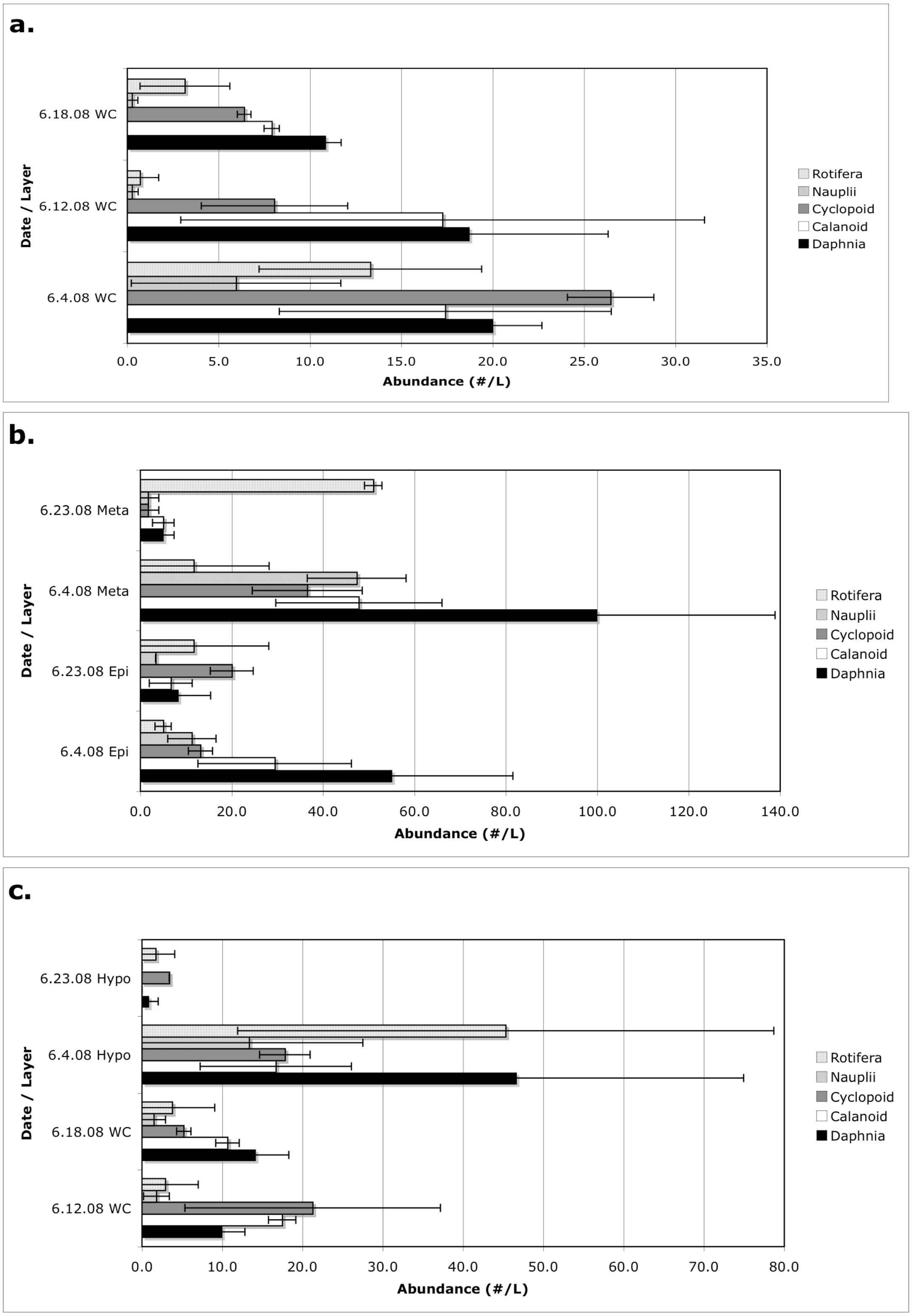


Fig. 5 Zooplankton collections were done at the north arm site for the whole water column (a.) as well as the Epilimnion and the Metalimnion (b.) Collections were done at the east arm site at the Hypolimnion and the whole water column (c.). Decreased zooplanktons levels were observed throughout the month with a few exceptions of smaller zooplankton.